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PRODUCTIVITY AND THE DENSITY OF ECONOMIC ACTIVITY

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ABSTRACT

Two different models - one based on local geographical externalities and the other on the variety of only locally available intermediate services - are shown to give rise to a simple, estimable relation between employment density and productivity. Using data on gross state output for the U.S., we find that agglomeration more than offsets congestion effects in denser areas. While our estimate of the elasticity of productivity with respect to density is small, it explains more than 50% of the observed state productivity differences, given the large differences in density.

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1. *Introduction*

Externalities and other sources of increasing returns in the aggregate technology provide a foundation for a number of new developments in aggregate economics. In fluctuations theory, increasing returns due to externalities seem a promising way to explain the volatility of output — the volatility is a puzzle in a convex neoclassical economy. In growth theory, aggregate increasing returns permits endogenous growth, also prohibited by neoclassical technology. And the recent upsurge of interest in the theory of regional and urban agglomeration rests on increasing returns associated with transportation and other coordination costs.

Previous research (Hall [1990]) has suggested that increasing returns has an important role in explaining year-to-year movements in productivity. Caballero and Lyons [1992] argued that externalities are the most persuasive explanation of the observed extent of increasing returns. Earlier work has also pointed out the close connection between the study of the distribution of economic activity over time and over space (Hall [1991]). There is a substantial theoretical and empirical literature on agglomeration effects relating to the size of cities. Our purpose in this paper is to look at the spatial dimension empirically within a framework where spatial density appears explicitly.

The source of increasing returns studied here is density. By density we mean simply the intensity of labor and capital relative to

physical space. Density is high when there is a large amount of labor and capital per square foot. If technologies have constant returns themselves, but the transportation of products from one stage of production to the next involves costs that rise with distance, then the technology for the production of all goods within a particular geographical area will have increasing returns — the ratio of output to input will rise with density. If there are externalities associated with the physical proximity of production, then density will contribute to productivity for this reason as well. And a third source of density effects is the higher degreee of beneficial specialization possible in areas of dense activity.

We view the various goods and services produced in an area as joint products. Jointness arises from transport costs even if the local technologies for the goods are not themselves joint. As a practical matter, we measure output as value added, although, as usual, the assumptions needed to make the use of value added completely rigorous are quite stringent.

The finest level of geographical detail in the United States for which reliable data on value added have been assembled appears to be the state level. Thus the observations on output are for the 50 states and the District of Columbia. But the average density of activity for a state is a meaningless concept. Most of the area of the United States supports essentially no economic activity at all. To get both, a meaningful measure of density, as well as a sensible specification for the geographical

extend of the spillovers, we have used much more detailed data by county. This work views the unit of production to be the labor, capital, and land present in a county. Estimation involves dealing with the aggregation from the county to the state level. In effect, we create an index of inputs for each state, adjusted for density at the county level. The index depends on the extent of increasing returns. The estimate of increasing returns is the one that generates a cross-sectional pattern of the input index that most closely matches the pattern of value added across states.

Related Agglomeration Literature

The economics of agglomeration began with Marshall [1920], who emphasized technological spillovers from one firm to another one nearby. Henderson [1974] formalized Marshall's ideas and demonstrated — building on work by Mills [1967] — that, in an equilibrium, disamenities from agglomeration on the side of households offset the productivity advantages on the side of firms.

A second branch of the literature on agglomeration hypothesizes economies of scale internal to firms. Mills [1967] was an early contributor. An essential task with internal increasing returns is to offer a coherent theory of the firm and its market. Mills assumed that all goods are produced by monopolists. More recent papers use a

monopolistically competitive market structure to study agglomeration with internal increasing returns to scale. Abdel-Rahman [1988], Fujita [1988 and 1989] and Rivera-Batiz [1988] employ the well known formalization of monopolistic competition due to Spence [1976] and Dixit and Stiglitz [1977] to demonstrate that non-transportable intermediate inputs produced with increasing returns imply agglomeration. The essence of these models is that local markets with more activity enable a larger number of producers of differentiated intermediate inputs to break even. The production of final goods has higher productivity when a greater variety of intermediate inputs is available.

Empirical studies of agglomeration have focused on the city or industry size as determinants of productivity. Sveikauskas [1975], Segal [1976] and Moomaw [1981 and 1985] estimated the effect of city population on productivity. Henderson [1986] found that the productivity of firms increases with the size of the industry as measured by industry employment. All of these studies are seriously flawed by their reliance on unsatisfactory measures of output from the Census of Manufactures.

The focus of past theoretical and empirical work has been on the role of city size. We are not aware of any studies that have examined spatial density directly. We believe that density is a more satisfactory concept. City boundaries are arbitrary. Close calls, such as whether San Francisco and Oakland are the same or different cities, have an important effect in empirical work based on city size, but none at all in our approach based on density.

2. Models

Increasing returns due to externalities

The ideas of this paper are easiest to understand in models without capital. Land and labor are the factors of production. We begin with a model based on externalities. Let $f(n,q,a)$ be the production function describing the output produced in an acre of space by employing n workers (all space is considered equivalent). The acre is embedded in a larger area (a county, in our empirical work) with total output q and total acreage a. The last two arguments describe the density externality in a very general way. We make the further assumptions that the externality depends multiplicatively on a particular measure of density, namely output per acre, that the elasticity of productivity with respect to density is a constant, $(\lambda - 1)/\lambda$, and that the elasticity of the output on an acre with respect to employment on that acre is a constant, α:

$$f(n,q,a) = n^{\alpha}\left(\frac{q}{a}\right)^{\frac{\lambda-1}{\lambda}} \tag{2.1}$$

The labor employed in a county, n_c, is distributed equally among all the acres in the county. Thus total output in county c is

$$q_c = a_c\left(\frac{n_c}{a_c}\right)^{\alpha}\left(\frac{q_c}{a_c}\right)^{\frac{\lambda-1}{\lambda}} \tag{2.2}$$

The county-wide joint technology is described by the production function obtained by solving this equation for output:

$$\frac{q_c}{a_c} = \left(\frac{n_c}{a_c}\right)^{\gamma} \tag{2.3}$$

Here γ is the product of the production elasticity, α, and the elasticity of the externality, λ; α measures the effect of congestion and λ measures the effect of agglomeration. Only the product, γ, is identified in our data. Our empirical results show that the net effect favors agglomeration.

We turn now to aggregation to the state level. Let C_S be the set of counties covering state s. Output in state s is

$$Q_S = \sum_{c \in C_S} a_c^{-(\gamma - 1)} n_c^{\gamma} \tag{2.4}$$

The output/labor ratio across states is

$$Q_S/N_S = \frac{\sum_{c \in C_S} a_c^{-(\gamma - 1)} n_c^{\gamma}}{\sum_{c \in C_S} n_c} \tag{2.5}$$

We define the factor density index,

$$D_s(\gamma) \equiv \frac{\sum_{c \in C_s} a_c^{-(\gamma - 1)} n_c^{\gamma}}{\sum_{c \in C_s} n_c} \tag{2.6}$$

Letting d_c be employment per acre in county c, D_s be employment per acre in state s, and D be employment per acre in the United States, we can decompose the density index into three components:

$$D_s(\gamma) = D^{\gamma - 1} \left(\frac{D_s}{D}\right)^{\gamma - 1} \frac{\sum_{c \in C_s} \left(\frac{d_c}{D_s}\right)^{\gamma - 1} n_c}{\sum_{c \in C_s} n_c} \tag{2.7}$$

That is, the state density effect is the national effect times a state effect, which depends on the relation of overall state density to national density, times a factor that depends on the inequality of density within a state. The last factor is county density relative to state density raised to the power $\gamma - 1$, weighted by county employment.

Under neoclassical conditions, with γ less than one, the density factors would predict lower productivity in states with higher average density, and even lower productivity in states with some particularly dense, congested areas. But if agglomeration effects outweigh congestion effects, density has the opposite effect. States with higher average

density and higher inequality of density will have higher levels of productivity.

Increasing returns from the variety of intermediate products

A second model hypothesizes increasing returns in the production of local intermediate goods, as in Abdel-Rahman [1988], Fujita [1988 and 1989], and Rivera-Batiz [1988]. Let the production function for making the final good on an acre of land be

$$f(m,s) \;=\; m^{\alpha\beta}\, s^{\alpha(1-\beta)} \;; \tag{2.8}$$

here m is the amount of labor used directly in making the final good, s is the amount of a composite service input which cannot be transported outside the acre, $\alpha < 1$ describes decreasing returns to the two variable inputs on the acre, and β is a distribution parameter. The service composite, s, is produced from individual differentiated services, $x(t)$, indexed by type t, according to the constant elasticity of substitution production function,

$$s \;=\; \left[\int_0^z x(t)^{\frac{1}{\mu}}\, dt\right]^{\mu} . \tag{2.9}$$

Here z describes the variety of intermediate products produced — types 0 through z are available. The parameter $\mu \geq 1$ controls the substitutability of the intermediate products. The higher is μ, the less one product substitutes for others and the higher is the monopoly power of the producer of that product. Under standard Spence-Dixit-Stiglitz assumptions, μ is the markup of price as a ratio to marginal cost that the producer will set in order to maximize profit.

We further assume that it takes $x + v$ units of labor to produce x. With labor paid w, the intermediate product maker will charge a price of μw and make a profit of $x\mu w - xw - vw$. With free entry to the intermediate product business, this profit will be pushed down to zero — the fixed cost will just offset the operating profit from market power. The level of output at the zero-profit point is

$$x = \frac{v}{\mu - 1} . \tag{2.10}$$

Putting this common value for all the service inputs into the production function for the service composite, equation 2.9, we have

$$s = z^{\mu} x . \tag{2.11}$$

Production of s uses $z\,x$ units of intermediate inputs, so the productivity of the s-making process is $z^{\mu - 1}$. Because $\mu > 1$, productivity rises with the available variety of intermediate goods. Denser acres have

greater variety, because more intermediate services producers can break even. The result is a positive relation between density and productivity.

The Cobb-Douglas specification of the final output technology in equation 2.8 implies that the share of final output paid to labor employed directly is $\alpha\beta$; hence, $wm = \alpha\beta f(m,\ s)$. The share paid to land is $(1-\alpha)$. In a free entry equilibrium all output not paid to land accrues to labor, either directly or indirectly through the intermediate service business. Therefore, $wn = \alpha f(m,\ s)$, where n, as before, is total labor employed in the acre. Combined, these relationships imply that the equilibrium allocation of labor to direct employment in final goods production is governed by the share parameter:

$$m \quad = \quad \beta n \ . \tag{2.12}$$

The remaining share $(1-\beta)n$ of the labor makes intermediate services. Because we know the total amount of labor devoted to intermediate services and the amount of each one produced, we can solve for the number of those services:

$$z \quad = \quad (1-\beta)\frac{\mu-1}{\mu}\frac{n}{v} \ . \tag{2.13}$$

Intermediate product variety, as measured by z, is proportional to density, as measured by the number of workers, n, working on the acre.

Now we can insert the equilibrium value of z into equation 2.11

to determine s, and then put m and s into the production function for final goods to get the consolidated production function,

$$\phi\, n^{\gamma} \; . \tag{2.14}$$

Here ϕ is a complicated function of the other constants and the elasticity of the production function is

$$\gamma \;=\; \alpha[1 + (1-\beta)(\mu-1)] \;>\; \alpha \; . \tag{2.15}$$

Again, the parameter α describes congestion effects — lower productivity resulting from crowding more workers onto the same acre. To the extent that the differentiated intermediate goods are important ($\beta < 1$) and they are not good substitutes for each other ($\mu > 1$), there is a countervailing effect favoring higher density, because it makes possible a greater variety of the intermediate products. With a high enough μ and a low enough β, the production function could have increasing returns, where the favorable effect of density outweighs the congestion effect.

In this equilibrium the market provision of intermediate inputs is inefficient due to distortions from monopoly pricing. We have worked out the alternative where the quantity and variety of intermediate services is optimal, either because of government intervention or vertical integration. The resulting elasticity of output with respect to total labor is the same as for the monopolistic competition case.

Now if we renormalize the measurement of the quantities to make $\phi = 1$ and assume, as before, that labor is distributed uniformly across the acres of a county, we have the county production function,

$$\frac{q_c}{a_c} = \left(\frac{n_c}{a_c}\right)^{\gamma} . \tag{2.16}$$

Aggregation to the state level proceeds exactly as before. There are no observational distinctions between the externalities model and the intermediate product variety model. Both provide a theoretical foundation for the same estimation procedure in state data.

Extensions with capital and differences in productivity across states and across time

Now let the production function giving output at date t in state s produced in county c on an acre of space by employing n workers and k machines be:

$$A_{t,s}\left((e_{t,s}n)^{\beta}k^{1-\beta}\right)^{\alpha}\left(\frac{q_{t,c}}{a_c}\right)^{\frac{\lambda-1}{\lambda}} . \tag{2.17}$$

Here $A_{t,s}$ is a Hicks-neutral technology multiplier at date t in state s and $e_{t,s}$ denotes the efficiency of labor. As before, the elasticity α is less than one by the amount of land's share in factor payments. The quantities of

labor and capital employed in a county, $n_{t,c}$ and $k_{t,c}$, are distributed equally among all the acres in the county. Thus total output in county c at time t is

$$q_{t,c} = a_c A_{t,s}\left[\left(\frac{e_{t,s}n_{t,c}}{a_c}\right)^{\beta}\left(\frac{k_{t,c}}{a_c}\right)^{1-\beta}\right]^{\alpha}\left(\frac{q_{t,c}}{a_c}\right)^{\frac{\lambda-1}{\lambda}} \qquad (2.18)$$

Solving for output, we get:

$$\frac{q_{t,c}}{a_c} = A_{t,s}{}^{\lambda}\left[\left(\frac{e_{t,s}n_{t,c}}{a_c}\right)^{\beta}\left(\frac{k_{t,c}}{a_c}\right)^{1-\beta}\right]^{\gamma} \qquad (2.19)$$

Again, γ is the product of the production elasticity, α, which is less than one, and the elasticity from the externality, λ, which is greater than one. If γ exceeds one, agglomeration effects dominate congestion.

To deal with capital, we make the assumption that the rental price of capital, r_t, is the same everywhere. Then we use the factor demand function to substitute the factor price for the factor quantity. That is,

$$\frac{k_{t,c}}{a_c} = \frac{\alpha(1-\beta)}{r_t}\frac{q_{t,c}}{a_c} \ . \qquad (2.20)$$

Thus county technology becomes

$$\frac{q_{t,c}}{a_c} = \phi\, r_t^{-\,\omega} A_{t,s}^{\frac{\theta}{\alpha\beta}} \left(\frac{e_{t,s} n_{t,c}}{a_c} \right)^{\theta} \tag{2.21}$$

where ϕ is a constant,

$$\omega \equiv \frac{\gamma(1-\beta)}{1-\gamma(1-\beta)}\ , \tag{2.22}$$

and

$$\theta \equiv \frac{\gamma\beta}{1-\gamma(1-\beta)}\ . \tag{2.23}$$

Using definition 1.6 and equation 2.21 we can express average productivity at date t in state s as:

$$\frac{Q_{t,s}}{N_{t,s}} = \phi\, r_t^{-\,\omega} A_{t,s}^{\frac{\theta}{\alpha\beta}}\, e_{t,s}^{\ \theta}\, D_{t,s}(\theta). \tag{2.24}$$

Under these alternative assumptions, the index of density has the same functional form with the elasticity θ in place of γ. Then the underlying value of γ can be calculated from equation 2.23. The relation between γ and θ for $\beta = .7$ is

γ	θ
1.000	1.000
1.025	1.036
1.050	1.070
1.075	1.110
1.100	1.150

Thus an elasticity of, say, 1.15 corresponds to an index of increasing returns of 1.1. For values close to 1, as found in our empirical work, the overstatement of γ associated with the treatment of capital is small. The extension of the variety model is analogous.

In order to transform equation 2.24 into a form which can be estimated, we have to make assumptions regarding the stochastic specification and the way observables affect the efficiency of workers. Concerning the former, we think of state productivity $A_{t,s}$ as being lognormally distributed about an underlying nationwide level A_t. We also want to allow for mismeasurement in state productivity. The measurement error has mean zero and again is taken to have a lognormal distribution. Regarding the latter, we use education to characterize the efficiency of labor. We choose the constant elasticity specification $e_{t,s}=E_{t,s}^{\delta}$, where $E_{t,s}$ denotes average years of education in state s at

date t. Using these relationships in equation 2.24 and taking natural logarithms yields:

$$\begin{aligned} \log \frac{Q_{t,s}}{N_{t,s}} &= \log \phi - \omega \log r_t + \frac{\theta}{\alpha\beta} \log A_t + \theta\delta \log E_{t,s} + \\ &\quad \log D_{t,s}(\theta) + u_{t,s}. \end{aligned} \tag{2.25}$$

Here $u_{t,s}$ is a weighted sum of the measurement error and the deviation of state productivity from the underlying level in the nation. We assume that $E\, u_{t,s}\, u_{t',s'} = 0$ for $s \neq s'$ and $E\, u_{t,s}\, u_{t',s} = \rho^{|t-t'|}\sigma^2$ for all s. In other words we assume both the random deviation of state productivity from the nationwide trend and the random measurement error for any state are correlated across time.

3. *Equilibrium*

How can states or counties be in equilibrium with different densities? This question arises if γ exceeds 1. Under neoclassical assumptions, density should be equal everywhere. The marginal product of labor is lower in a denser area, and there are arbitrage profits or a higher standard of living available by moving a worker from a dense area to a less dense one. On the other hand, with γ greater than one, the

worker is more productive when moved to a denser area. Absent other considerations, the only equilibrium is for employment to concentrate in a single county.

The simplest answer, and a realistic one, is that some workers prefer to live in areas that turn out to be less dense. These workers are willing to accept the lower wages in those locations. The preference could be, but need not be, a preference for lower density itself. The preference could also take the form of devotion to a location that is not an agglomeration point. Finally, it should be noted that if households value land, its price drives a wedge between the product wage and the consumption wage.

In equilibrium, there are no incentives to move for either firms or households. The marginal cost of production is equalized across all counties as the decrease in marginal cost associated with higher density is offset by higher product efficiency wages and higher land prices. Households find that differing product wages are counterbalanced by any of the consideration described above. A related implication is that better educated workers live in denser areas.

4. Data

The data needed for estimation are available for the years 1988 and 1989. The data cover the private non-proprietary economy. That is, data on labor input at the county level includes only employees, not the self-employed. The corresponding measure of output at the state level is Gross State Product less proprietors' income. We use GSP at sellers' prices; we do not include indirect business taxes in the output measure.

Data on employment by county are compiled by the Bureau of the Census and published in ***County Business Patterns.*** The sums of these employment estimates at the state level are not exactly the same as the state employment data published by the Bureau of Labor Statistics in ***Employment and Earnings.*** Therefore we use adjusted data available from the Bureau of Economic Analysis.

Data on the area of each county are published by the Bureau of the Census in the ***County and City Data Book.***

Data on Gross State Product and proprietors' income are compiled by the Bureau of Economic Analysis of the Department of Commerce and described in BEA Staff Paper 42, ***Experimental Estimates of Gross State Product by Industry.*** These data are conceptually far superior to those used in previous work on spatial differences in productivity. Moomaw [1985], Sveikauskas [1975], and Segal [1976] all measure output as the concept of value added or total value of production used in the Census of Manufactures. This concept omits all

services either purchased in the market or obtained from corporate headquarters. It is hard to see how Census of Manufactures value added could be used for any purpose in production economics, but it is a particularly unusable concept for agglomeration issues. Because there is likely to be less vertical integration in big cities or in dense areas, firms in those places are likely to purchase more services than do their counterparts in less dense areas. Moreover, a plant in a dense area is more likely to be close to its corporate headquarters and therefore more dependent on it for transferred services. For both reasons, studies using Census of Manufactures value added will overstate the productivity advantage of cities or dense areas. The research of Henderson [1986] uses total value of production, also from the Census of Manufacturers. Compared to the value added data this concept has the added disadvantage of double-counting inputs traded within an industry. Our data are based on a careful allocation of purchased and transferred services by industry at the state level. Gross State Output is a much more satisfactory measure of output than is the Census of Manufactures concept of value added.

Our theoretical formulation assumes that all land is equivalent. Therefore, we use data on state output and county employment for the non-agricultural sector. We also do not include measures of inputs other than labor, capital, and land. In a few states, natural resources are sufficiently important to make our output measure unrealistic. On this basis, we excluded all states where the mining contributes more than 10%

of private GSP. These states are Alaska, Louisiana, New Mexico, West Virginia and Wyoming. In some other states, notably Nevada, natural resources probably explain the size of our observed residual.

Our data on education are from the Bureau of the Census. For the year 1989 the Bureau publishes the percentages of the states' population (25 years or older), which went to high school or college for 4 or more years in the ***Current Population Report Series*** under the heading: "***Educational Attainment in the United States: March 1989 and 1988.***" We obtained unpublished data for 1988 from the Bureau.

5. Identification and estimation

We make two alternative identifying assumptions. First we assume that the random element of output per worker is uncorrelated with density and average education levels. This assumption amounts to saying that density and education are measured with little error and do not respond to the random element of productivity. Because it appears that much of the noise in productivity across states comes from measurement error, this assumption is not as strong as it may seem at first.

Under this identifying assumption, we estimate the returns-to-scale parameter, γ, and the elasticity of average product with respect to education, $\eta \equiv \theta\delta$, by nonlinear generalized least squares. We recover an

estimate of the standard errors from the curvature of the concentrated likelihood function. Finally, we treat the underlying productivity at the national level in different years and annual changes in the rental rate of capital as fixed effects.

Comparing our results to the econometric literature concerned with estimating the effect of education on earnings, we find that once we control for the density of economic activity, our estimates of the effect of education on earnings are smaller than estimated in these studies. However the differences are not significant, and in fact, if we restict η to the values estimated by Davis [1992], our estimate of the returns-to-scale parameter drops only slightly.

Our alternative identifying assumption is that there is an exogenous characteristic of states that can function as an instrumental variable for the density index. The corresponding estimator is nonlinear instrumental variables. The characteristic we use is the presence or absence of a deep water port in the state. The historical pattern of agglomeration in the United States was around ports. The presence or absence of a port is eligible as an instrument only if ports are, today, relatively unimportant in determining productivity. Thus our hypothesis is that ports were an important historical source of agglomeration, but that their influence today is almost entirely through the legacy of agglomeration and not through a significant current contribution to productivity.

Under this assumption we find that the returns-to-scale

parameter increases slightly, while the elasticity of earnings with respect to education falls. Finally we again estimate the returns-to-scale parameter γ restricting η to the value estimated by Davis [1992].

6. *Results*

The least squares estimate of θ is 1.050 with a standard error of .008. The elasticity of average product with respect to education, η, is .46 with a standard errror of .40. The R^2 of the regression is .51. Davis [1992], using data on individuals, estimates the elasticity of earnings with respect to education to lie between .80 and 1.35. Consequently our estimate is less than one standard error away from Davis's lower estimate. Restricting η to unity results in θ dropping to 1.047 with a standard error of .006. The instrumental variable estimates for θ and η are 1.052 and .41, with standard errors of .010 and .48 respectively. Restricting η to unity in the instrumental variable estimation leaves both the estimate of θ and the standard error unchanged. The instrumental variable estimate of θ corresponds to a returns-to-scale parameter γ of 1.036.

Table 1 shows the factor density index for θ=1.052, average years of education, and the private, non-agricultural gross state product per worker. The states are ranked in declining order of density. The densest area for which reliable output data is available is Washington,

Table 1: Density, Education and Average Productivity (1989)
Theta=1.052

	Density-Index	Average Years of Education	Gross State Product per Worker (1989 $)
D.C.	1.58	13.85	45,621
NEW YORK	1.51	13.43	43,494
NEW JERSEY	1.42	13.54	46,021
MASSACHUSETTS	1.41	13.73	38,379
ILLINOIS	1.40	13.33	40,048
MARYLAND	1.39	13.72	35,923
RHODE ISLAND	1.38	13.40	31,339
CONNETICUT	1.38	13.53	43,121
CALIFORNIA	1.37	13.58	42,843
PENNSYLVANIA	1.35	13.26	35,953
Top 10 Average	1.42	13.54	40,274
OHIO	1.35	13.18	37,223
DELAWARE	1.35	13.41	36,779
MICHIGAN	1.34	13.16	39,404
HAWAII	1.34	13.46	36,964
MISSOURI	1.34	13.25	35,357
MINNESOTA	1.33	13.56	36,459
FLORIDA	1.32	13.33	31,683
TEXAS	1.32	13.32	39,138
GEORGIA	1.32	13.08	36,552
COLORADO	1.30	13.77	33,929
INDIANA	1.30	12.99	35,558
WISCONSIN	1.30	13.39	34,187
TENNESSEE	1.30	12.79	34,170

NORTH CAROLINA	1.28	13.05	34,165
KENTUCKY	1.28	12.90	36,288
WASHINGTON	1.28	13.64	33,981
UTAH	1.28	13.67	33,032
NEBRASKA	1.27	13.44	30,943
OKLAHOMA	1.26	13.23	34,588
NEW HAMPSHIRE	1.26	13.53	37,281
OREGON	1.26	13.48	34,091
SOUTH CAROLINA	1.25	13.10	31,388
KANSAS	1.24	13.61	35,704
ALABAMA	1.24	12.82	34,685
ARIZONA	1.22	13.43	34,052

IOWA	1.22	13.23	33,447
MAINE	1.21	13.29	33,884
VERMONT	1.21	13.65	35,008
ARKANSAS	1.20	12.79	32,954
MISSISSIPPI	1.19	12.91	33,560
NEVADA	1.18	13.19	39,180
IDAHO	1.15	13.15	31,325
SOUTH DAKOTA	1.14	13.40	27,039
NORTH DAKOTA	1.11	13.45	32,443
MONTANA	1.09	13.45	32,901
Bottom Ten Average	1.17	13.25	33,174

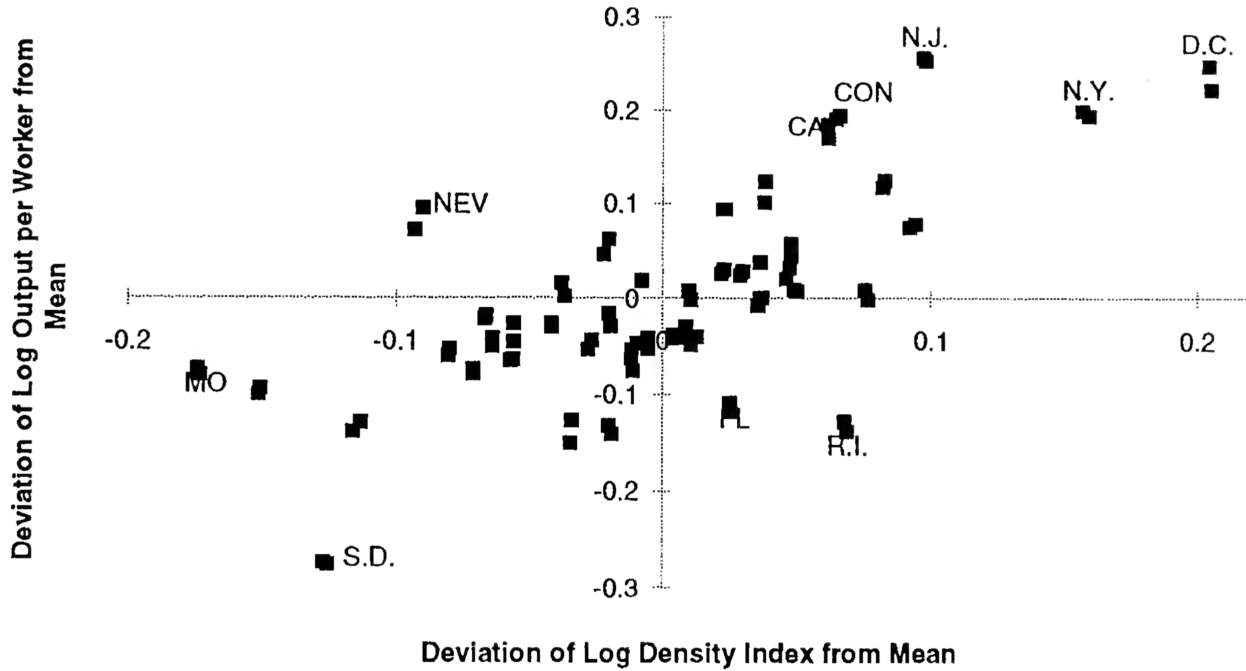
D.C. Not surprisingly, New York ranks second. It is the extreme concentration of employment in New York City that gives the high value of the density measure. In fact, New York City comprises two of the five densest counties: New York County (with a factor density index of 1.81) and Queens County (with a factor density index of 1.54). This makes New York County 18% more productive than New York State, the state with the third highest average productivity in our sample.

The other dense states are the highly urbanized states of the northeast plus Illinois and California. The least dense states are the thinly populated states of northern New England, the south, and the southwest. It is important to note that density is not just a measure of the inequality of distribution of the work force across counties — it is also dependent on the actual density in the counties where employment is significant.

The third column of Table 1 shows non-proprietary output per worker by state for the year 1989. Output per worker varies from \$27,039 in South Dakota to \$46,021 in New Jersey. This amounts to a 70% difference between the most and the least productive state.

The positive correlation of density and productivity is immediately apparent from Table 1 and Figure 1. There are a number of outliers that call for further investigation: Most conspicuous is Rhode Island, which is just as dense as its neighbors but has productivity at the level of the very least dense states. Montana and Nevada have much higher productivity than their low densities would predict. Natural

FIGURE 1: Output per Worker and Density, 1988 and 1989
(Theta=1.052)



resources are part of the explanation. (In Montana and Nevada mining contributes more than 5% to private state product.)

Table 2 decomposes the log density index into a state effect and a distribution effect. The column headed "State Effect" gives the part of the state effect arising from the average density of the entire state. For example, if the density of employment in Massachusetts fell to the national level, while the distribution of employment over the counties remained unchanged, then this would result in a 13 percent drop in average product. The "Distribution Effect" measures the part of the state productivity effect attributable to an unequal distribution of employment over counties. For example, productivity in New York would fall by 15 percent if employment were to be allocated employment uniformly across the area of the state. Nebraska, Nevada, Oregon and Utah are examples of a states with great inequality across counties but low density, because their major metropolitan areas have relatively low levels of employment per acre.

Among the counties with the smallest density indices are Garfield County (Montana), Kimball County (Nebraska), Newton County (Arkansas) and La Paz County (Arizona). We estimate that workers in these counties produce less than half the output of a worker in New York City.

Figure 2 plots the relation between average years of education and average output for all states examined (in the years 1988 and 1989). Finally, figure 3 plots output per efficiency worker against density.

Table 2: Density and Average Productivity (1989)
State and Distribution Effects, Theta=1.052

	State Effect	Distribution Effect	Gross State Product per Worker (1989 $)
D.C.	0.28	0.00	45,621
NEW YORK	0.08	0.15	43,494
NEW JERSEY	0.13	0.04	46,021
MASSACHUSETTS	0.12	0.04	38,379
ILLINOIS	0.05	0.11	40,048
MARYLAND	0.09	0.06	35,923
RHODE ISLAND	0.13	0.01	31,339
CONNETICUT	0.12	0.02	43,121
CALIFORNIA	0.04	0.09	42,843
PENNSYLVANIA	0.06	0.06	35,953
Top 10 Average	0.11	0.06	40,274
OHIO	0.06	0.06	37,223
DELAWARE	0.08	0.04	36,779
MICHIGAN	0.03	0.08	39,404
HAWAII	0.04	0.07	36,964
MISSOURI	-0.01	0.11	35,357
MINNESOTA	-0.02	0.12	36,459
FLORIDA	0.05	0.05	31,683
TEXAS	-0.02	0.12	39,138
GEORGIA	0.01	0.08	36,552
COLORADO	-0.05	0.14	33,929
INDIANA	0.03	0.05	35,558
WISCONSIN	-0.03	0.11	34,187
TENNESSEE	0.02	0.06	34,170

NORTH CAROLINA	0.03	0.04	34,165
KENTUCKY	0.00	0.07	36,288
WASHINGTON	-0.01	0.08	33,981
UTAH	-0.08	0.14	33,032
NEBRASKA	-0.08	0.13	30,943
OKLAHOMA	-0.05	0.10	34,588
NEW HAMPSHIRE	0.02	0.03	37,281
OREGON	-0.06	0.10	34,091
SOUTH CAROLINA	0.01	0.03	31,388
KANSAS	-0.06	0.09	35,704
ALABAMA	-0.01	0.04	34,685
ARIZONA	-0.06	0.07	34,052

IOWA	-0.03	0.05	33,447
MAINE	-0.04	0.05	33,884
VERMONT	-0.02	0.02	35,008
ARKANSAS	-0.04	0.04	32,954
MISSISSIPPI	-0.04	0.03	33,560
NEVADA	-0.10	0.08	39,180
IDAHO	-0.11	0.07	31,325
SOUTH DAKOTA	-0.13	0.07	27,039
NORTH DAKOTA	-0.13	0.05	32,443
MONTANA	-0.16	0.06	32,901
Bottom Ten Average	-0.08	0.05	33,174

FIGURE 2: Output per Worker and Average Years of Education

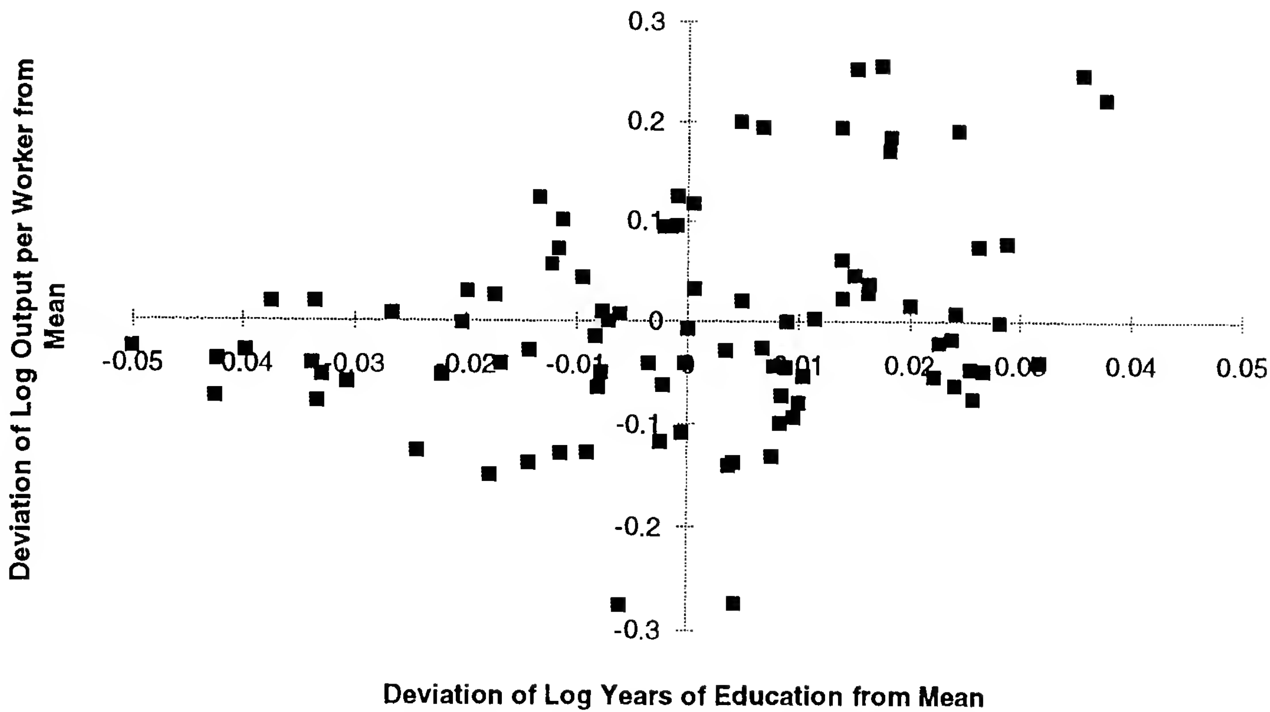
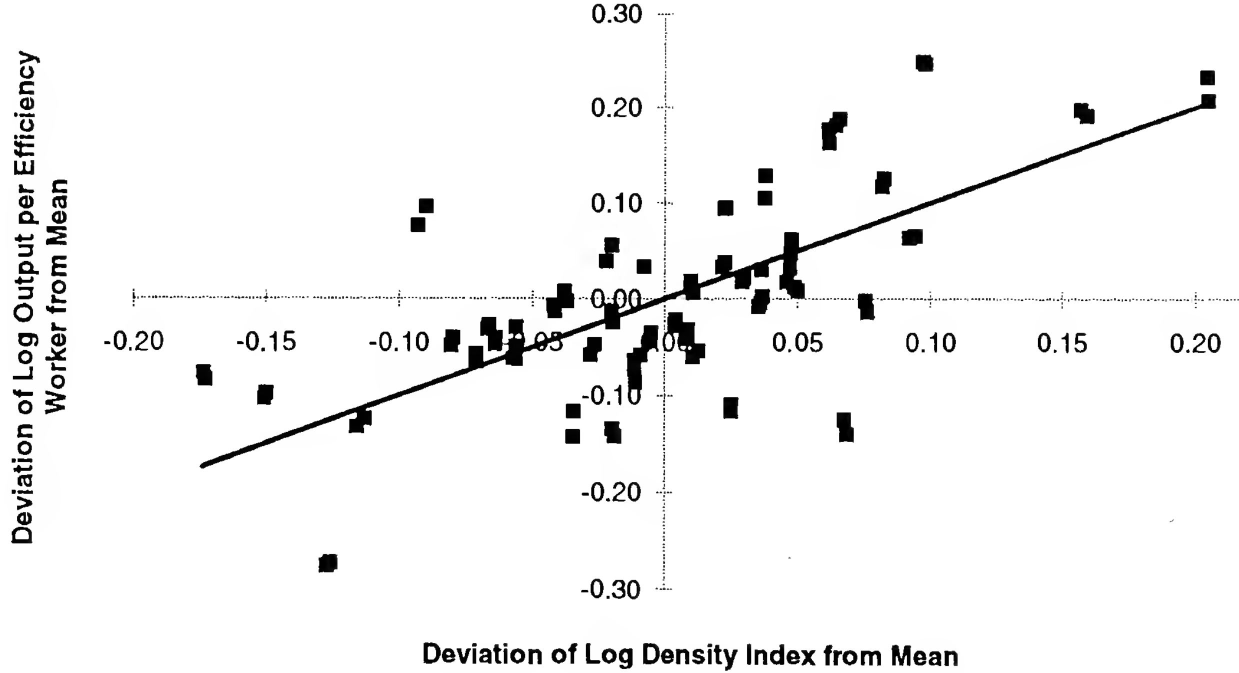


FIGURE 3: Output per Efficiency Worker and Density, 1988 and 1989 (Theta=1.052)



7. *Concluding remarks*

Two different theoretical models — one based on local geographical externalities and the other on the variety of only locally tradable intermediate services — give rise to a simple, estimable relation between employment density and productivity. We believe that our approach based on density is a better way to characterize agglomeration effects previously associated with presence in a city or city size. Using data on state output, we find that agglomeration more than offsets congestion effects in denser areas. Our estimate of the elasticity of productivity with respect to density is about .04. Given very large differences in density, this value corresponds to large geographical differences in productivity. Earlier estimates of the elasticity of productivity with respect to city size have generally been somewhat higher, but the difference may arise from the use of defective measures of output from the Census of Manufactures.

Our work has two implications for growth theory. First, externalities and locally tradable services weaken the link between differences in output per worker and differences in returns on capital; the externality from production density described above, for example, counteracts the standard neoclassical effect of a high capital-intensity on the return to capital. Hence, with externalities productivity differentials between regions disappear slower than otherwise. See Barro and Sala-i-Martin [1991] for empirical evidence on the slow convergence of Gross

State Product in the U.S. and Ciccone [1992] for a theoretical framework where differences in output per worker arise endogenously and persist even so factors are perfectly mobile.

Second, rising density over time is an important factor in growth. Large U.S. cities are denser now than in earlier centuries, and a much larger fraction of the population is employed in cities or other dense areas. We plan to apply our estimates to historical data on the distribution of employment by county to measure the part of total growth that can be associated with rising density.

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